BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 08019

SUBJECT: Comparison of Reusable and Non-Reusable Mars Excursion Modules For Multiple Landing Missions - Case 105-4

DATE: August 11, 1970

FROM: M. H. Skeer

ABSTRACT

[redacted]

This memorandum documents work performed in the summer of 1969 in support of Space Task Group planning activities. At that time manned planetary program emphasis was directed towards ambitious Mars landing missions with many landings per mission. It appeared that totally reusable surface landing systems might offer some advantages and a preliminary analysis was undertaken to examine the tradeoffs involved. Interest in these missions has been recently revived in planning exercises addressing capabilities by the year 2000.

A Mars Excursion Module (MEM) is utilized for crew and cargo delivery from Mars capture orbit to the surface and return. Herein, possible MEM operational modes which could have a substantial impact on MEM design and the overall mission plan are evaluated, with particular emphasis on reusability. The effect of orbital and surface refueling, which may be achievable in association with advanced bases, is also discussed.

It is concluded that reusable vehicles are significantly heavier than their nonreusable counterparts and would most likely be practical only in association with low circular Mars capture orbit operations. Propellant required for a reusable MEM refueled from orbit weighs more than the nonreusable vehicle (propellant plus dry weight) by a factor of approximately two and a half. A Mars mission performed with reusable MEM's would therefore have greater initial weight than a similar mission utilizing nonreusable MEM's regardless of the number of surface landings. Reusable MEM's refueled from orbit would be justifiable only if recurring costs of nonreusable vehicles overshadowed the additional transportation costs to accommodate the increased mission weight and the additional cost of reusable MEM vehicle development.

A notable savings in reusable vehicle weight can be achieved if refueling on the surface is possible. Such a system could be attractive for surface to orbit operations on advanced Mars missions. However, manufacturing propellants on the surface of Mars for the planetary spacecraft return trip to earth requires such a large number of refueling flights as to appear impractical.

(NASA-CR-113383) COMPARISON OF REUSABLE AND NONREUSABLE MARS EXCURSION MODULES FOR MULTIPLE LANDING MISSIONS (Bellcomm, Inc.) 24 p

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MEMORANDUM FOR FILE

Introduction

This memorandum documents work performed in the summer of 1969 in support of Space Task Group planning activities. At that time manned planetary program emphasis was directed towards ambitious Mars landing missions with many landings per mission. It appeared that totally reusable surface landing systems might offer some advantages, and a preliminary analysis was undertaken to examine the tradeoffs involved.

In the Integrated Program of Space Utilization (References 1-3) cislunar missions are to be performed with reusable propulsion modules and long term hardware. Key propulsion and mission module elements developed for cis-lunar operations would be extended for use on manned plane-tary missions. In accordance with the philosophy of reus-ability it is of interest to examine the impact of reus-ability and the configuration and performance of the Mars Excursion Module (MEM) utilized for crew delivery from Mars capture orbit to the surface and return. In this memorandum possible operational modes for the MEM (consis-tent with other hardware elements in the Integrated Program) which could have a substantial impact on MEM design and the overall mission are evaluated with particular emphasis on MEM reusability. Four generic classes of MEM vehicles are compared:

- Nonreusable vehicles with one or two ascent stages,
- Reusable vehicles refueled from the planetary spacecraft in Mars parking orbit, and
- Reusable vehicles refueled on the Martian surface utilizing propellants manufactured in situ.

It is presumed that for reusable concepts substantial amounts of propellant are either delivered to Mars orbit with the mission module, or manufactured at a large permanent base established prior to time of operation.

A system optimization of these concepts has not been undertaken herein; rather estimated vehicle characteristics are employed for performance comparisons. Neither has an attempt been made to address such factors as differences in development cost between reusable and nonreusable MEM systems, packaging efficiency for launch, or orbital refueling and refurbishing operations, some of which could challenge the feasibility and practicality of the reusable approach.

MEM Design Concepts

Nonreusable MEM's have been considered in some detail in previous studies (Reference 4 and 5) in which design and scaling relationships have been formulated. Figures 1 and 2 show two such concepts. In both cases the MEM is braked aerodynamically from Mars capture orbit. Terminal maneuvering which includes contingency for final targeting corrections and hover time, is provided by propulsive braking.

It has been found to be economical to separate the ascent capsule from the surface shelter to minimize MEM gross weight, even though two crew compartments are required. These studies also show that MEM gross weight is extremely sensitive to both ascent capsule weight and the ascent velocity for return to the planetary spacecraft parking orbit. Thus the ascent capsule (comprising about 5% of MEM gross weight) is the only segment of the vehicle returned.

Reusability would preclude the use of separate compartments since all surface systems would be recovered. The ascent capsule is therefore considerably larger in the reusable case when used as a shelter on extended surface missions.

Mars Parking Orbit Tradeoffs

Low circular orbits at Mars are attractive for the MEM since the velocities to and from the surface are minimized; however, these orbits result in high overall mission weight because capture and departure velocities for the planetary spacecraft are substantially increased. Conversely, high elliptical orbits which are desirable for the inter-planetary spacecraft penalize the MEM due to added velocity for surface to orbit return. If multiple surface landings are performed the tendency would be towards the low circular orbits favoring the MEM. Minimization of overall mission weight is however dependent on numerous factors such as spacecraft propulsion selection, mission class and year, and gross payload at Mars. No attempt at orbit optimization is undertaken here.

Scaling Law Relationships

Reusable vehicles are conceptually similar to the nonreusable designs with the exception that entry systems, surface shelter, and reusable payload are returned. The ascent capsule and surface shelter are combined in a single compartment which, as noted, substantially increases the return payload to orbit by comparison to the nonreusable case.

The following scaling relationships are assumed:

Entry Systems - The MEM is packaged in an Apollo type entry shell configuration. Entry systems are a linear function of gross weight at entry, equal to 15 to 20% of gross entry weight depending on vehicle size. (This relationship is based on characteristics of the MEM design in Reference 4.) For the reusable MEM systems, it is assumed that only minimal vehicle refurbishment is permitted and the complete vehicle is returned to orbit.

Propulsion - LH_2/LO_2 propellants with an I_{sp} of 460 sec are presumed. Selection is based on similarity with other Integrated Program propulsion systems and the assumption that LO_2/LH_2 propellant can be manufactured on the Martian surface.* Propellant fractions (ratio of propellant weight to propellant plus propulsion system inerts) of .85, .87, or .89 are presumed, depending on propulsion system size.

Impulsive Velocity - Ascent velocity which is determined by the planetary spacecraft parking orbit can vary from 15,000 fps for low circular parking to 20,000 fps for high

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*Previous studies have suggested that packaging constraints of the aerodynamic shell may preclude selection of LO_2/LH_2 for some MEM designs. Theoretical performance of the LO_2/LH_2 stages approximates that of $FLOX/CH_4$ stages, an acceptable alternative, and scaling laws derived in Reference 4 suggest the weights of the two systems are similar. Thus vehicle size determined for the LO_2/LH_2 system would be generally applicable to either case.

elliptical parking orbit. (These include contingencies for plane change and rendezvous corrections.) Terminal velocity after atmospheric braking is canceled propulsively. Approximately 3,000 fps is required. The total impulsive velocity (ascent plus descent) is therefore from 18,000 fps to 23,000 fps.

Scaling laws for the various configurations are presented in Table 1. Scaling relationships are expressed in terms of a non-dimensional "growth factor" defined to be the ratio of spacecraft gross weight, W_g (fully fueled) to ascent payload, P_a (ascent capsule plus discretionary payload). The growth factor is a function of the following parameters:

K = descent payload/ascent payload

r_a = ascent mass ratio $e^{(\Delta V_a/Ig)}$

r_d = descent mass ratio $e^{(\Delta V_d/Ig)}$

λ = propellant weight/propellant weight + propulsion system weight

μ = ratio of entry systems weight to gross weight at entry.

K relates the descent payload to ascent payload and is dependent on the peculiar characteristics of the mission mode. r_a and r_d are derived from the assumed ascent and descent impulsive velocities, ΔV_a and ΔV_d, respectively λ and μ are the assumed vehicle mass characteristics.

Mission Mode Comparison

To determine the relative performance characteristics of the generic classes of MEM vehicles (i.e., nonreusable, reusable/orbit fueled, reusable/surface fueled) it is necessary to compare operations in association with specific mission mode requirements. For example, whereas a reusable vehicle might be prohibitively heavy for use as a surface base it could be competitive with nonreusable vehicles for crew logistics and cargo delivery missions. In this context four classes of missions are considered:

- Logistics - crew transport to and from the surface with limited payload, representative of a minimum mission in support of an existing base.

- Self Contained Surface Base - crew transport together with substantial surface shelter and payload for establishment of a self contained base with a duration of between 30 to 60 days.

- Cargo Delivery - delivery of one way cargos to the surface from orbit for supply of a large permanent or semi-permanent base.

- Fuel Delivery - delivery of propellants from the surface to the spacecraft for refueling the planetary spacecraft for its subsequent return to earth.

Comparison of the different MEM configurations also requires estimation of the relationship between ascent and descent payloads for similar types of missions. For example, the ascent payload for a reusable system includes the surface shelter whereas in the nonreusable case most of the payload remains on the surface and only a small crew capsule is returned.

Ascent capsule payload for the nonreusable MEM is on the order of 1,000 lbs/man, based on studies in References 4 and 5. This should be relatively independent of staytime since the ascent capsule is occupied only during arrival and departure times. The surface shelter weight is approximately 2,000 lbs/man (for 30 to 60 day staytime) and surface payload is about 1,000 lbs/man. Total landed payload for the nonreusable designs is estimated at 4,000 lbs/man for self contained surface base missions. Return payload would be equal to 1,000 lbs/man (the ascent capsule alone).

In the case of the reusable MEM it is likely that the shelter and large payload items (i.e., mobility systems, experiments, etc.) would be returned for reuse. Moreover the ascent capsule and shelter would probably be combined to achieve substantial reductions in weight relative to two separate compartments. For the logistics mission (transportation capsule only) the round trip payload is assumed to be 1500 lbs/man. This is 50% greater than the nonreusable case since systems which are required for the landing phase are returned for reuse on subsequent flights, in addition to the basic ascent system.

For the reusable surface base mission, round trip payload is assumed to be 3000 lbs/man,* as compared to 4000 lbs/man descent payload for the comparitive nonreusable base mission. The 1000 lbs/man saving is attributed to combining the shelter and ascent systems. For the cargo mission, it is presumed that the crew capsule is similar to that utilized on the logistics mission, with an additional 1500 lbs/man cargo payload delivered to the surface from orbit. The 1500 lbs/man is sufficient for extensive resupply and delivery of large integral surface payloads. In the propellant refueling case, the ascent payload, comprised of propellant delivered from the surface to orbit plus reusable containers and crew compartment, is arbitrarily assumed to be 4 times the descent payload. For comparison with other modes the descent payload is normalized to 1500 lbs/man yielding a 1500 lbs/man ascent payload and a 4500 lbs/man propellant capacity. These payload data are summarized in Table 2.

Performance Analysis

The results of the comparisons (based on Tables 1 and 2) are shown for several representative cases in Figures 3 and 4. (Assumed mass characteristics and payloads are noted on the figures.) Single stage and two stage logistics vehicles (Figure 3) operating from low circular orbit (15,000 fps) weigh 6,800 lbs/man and 6,000 lbs/man respectively. By comparison a reusable vehicle fueled on orbit weighs 26,000 lbs/man, and a reusable vehicle fueled on the surface weighs 12,700 lbs/man.** The maximum velocity achievable by an orbitally refueled vehicle is less than 18,000 fps, whereas the nonreusable and surface refueled vehicles can reach high elliptical orbit at 20,000 fps. Weights for the single stage and two stage vehicles when operating from high elliptical orbit are 13,400 lbs/man and 9,600 lbs/man respectively, and the weight of the surface fueled reusable vehicle is 35,000 lbs/man. Note that there is relatively little gain afforded by staging nonreusable vehicles.

The weights of the MEM vehicles required for performance of the surface base mission are given in Figure 4. The single stage nonreusable vehicle weights for low circular

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*lbs/man is a convenient way of relating the various payloads for purposes of comparing different classes of vehicles and missions.

**These figures refer to the gross weight of the fully fueled stage. Thus for the surface fueled vehicles this would be weight on the surface prior to liftoff. Maximum weight of orbitally fueled vehicles would be prior to separation from the planetary spacecraft.

and high elliptical orbits are 12,000 lbs/man and 18,000 lbs/man respectively, about twice that of the logistics vehicle. The orbitally fueled reusable vehicle weight is by comparison 52,000 lbs for low circular orbit, and cannot achieve the high elliptical orbit.

From this data it is observed that

- Reusable vehicles are significantly heavier than nonreusable vehicles and would most likely only be practical in association with low Mars capture orbit operations. The on-orbit refueling vehicle could not, in fact, achieve velocities much greater than 17,000 fps.

- A notable savings in reusable vehicle weight can be achieved if refueling on the surface is possible. This is because landing systems weight is substantially reduced when the stage enters the atmosphere devoid of propellants.

- Single stage nonreusable vehicles are almost competitive with two stage designs if propellant fractions of .85 are achievable.

Figure 5 shows a comparison of reusable and nonreusable MEM gross weight plus propellant delivered to low circular orbit for multiple landing missions. A three man logistics mission and three man 30 to 60 day base mission are selected as examples. The nonreusable MEM's operating from low circular parking orbit have gross weights of 20k and 35k for logistics and base designs respectively. Reusable MEM's have comparitive gross weights of 75k and 150k, or approximately four times the nonreusable MEM weight, for both cases. Weight breakdowns of the four designs are shown in Table 3. Approximately two thirds of reusable MEM gross weight is propellant which is resupplied on orbit for each landing. Note the curves in Figure 5 diverge because reusable MEM propellant weight is greater than total weight of the nonreusable MEM.

Propellant manufacture on the surface in contrast to refueling in Mars orbit (Figure 3) would enable the reusable 3 man logistics vehicle weight to be reduced from 75k to approximately 40k, about twice that of the nonreusable MEM. Manufacture of 27k of propellants would be required for each flight. This may be an attractive alternative on advance missions.

Figure 6 shows a comparison of reusable logistics vehicles modified to deliver a 1500 lb/man cargo complement as well as crew to the surface from orbit in support of a permanent or long term surface base. Delivery of 3 men plus 4500 lbs to the surface from low circular parking orbit requires MEM gross weights of 54,000 lbs and 100,000 lbs for surface fueled and orbit fueled vehicles respectively. A surface fueled vehicle from high elliptical parking orbit would weigh 150,000 lbs.

If the reusable MEM were to deliver fuel from the surface to low Mars orbit, (Figure 7) approximately 6 lbs of propellant would have to be manufactured for each lb of propellant delivered to the planetary spacecraft in parking orbit. This ratio is increased to 13 lbs for delivery of propellants to high elliptical orbit. Selection of the optimum planetary spacecraft parking orbit for refueling operations ultimately depends on such factors as total quantity of propellant, number of MEM fueling missions, and propellant manufacturing rate. For a Mars departure ΔV of 10,000 fps above low circular parking orbit and 4,000 fps for earth capture,* typical of conjunction class missions, 1.6 lbs of propellant is required for each lb of payload delivered to earth capture orbit. Consequently $6 \times 1.6 \cong 10$ lbs of propellant would have to be manufactured for each lb of payload returned to earth orbit.** The return of a 100,000 lb module and 20,000 lb inert stage would require manufacture of 1,200,000 lbs of propellant and transport of 200,000 lbs of propellant to orbit. These weights are respectively 1,300,000 lbs and 100,000 lbs for high elliptical orbit. In the case of departure from low circular orbit 15 fuel delivery flights by a vehicle of approximately 100,000 lbs gross weight (on the surface) would be required. Thus refueling of a planetary spacecraft from surface manufactured propellants does not appear practical.

---

*Return to high elliptical earth orbit

**Presuming an all chemical propulsion system

Conclusion

MEM reusability increases gross vehicle weight by approximately a factor of four and vehicle dry weight by a factor of two. For 10 landing missions the dry weight of the 10 nonreusable systems is 5 times as great as the reusable system dry weight. The quantity of propellant supplied to the reusable MEM by the planetary spacecraft exceeds the total weight of a nonreusable MEM by a factor of approximately 2 1/2. Total weight including propellant for refueling is greater for the reusable system regardless of the number of landings. This is true for minimum logistics flights as well as large self contained base missions. Reusable systems moreover, would require low circular parking orbits at Mars for efficient operations which further increases planetary spacecraft weight. Reusable MEM's would be justifiable only if recurring cost of nonreusable vehicles overshadowed the effect of these weight increases.

Manufacturing propellants on the surface of Mars for a return trip to earth does not appear practical compared to bringing propellants along for the round trip. Propellant manufacture does however offer promise for MEM surface to orbit operations.

1013-MHS-ab/klm

M. H. Skeer

Attachments
  Tables 1-3
  Figures 1-7

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2. Thompson, W. B., et.al., "Integrated Space Program, Manned Planetary Missions for the 1980's," Bellcomm Memo for File, B69 09015, August 6, 1969.

3. London, H. S., et.al., "Briefing on Manned Planetary Missions, Bellcomm Memo for File, B69 07093, July 30, 1969.

4. Definition of Experimental Tests for a Manned Mars Excursion Module, North American Rockwell Corp., Contract NAS9-6464, SD-67-755-2, January 1968.

5. Skeer, M. H., "Mars Excursion Module Ascent Propulsion Stage Design," Bellcomm TM-68-1013-3, July 8, 1968.

APPENDIX

This appendix presents the essentials of the deviation of scaling laws in Table 1.

List of Symbols

P_a = ascent payload

P_d = descent payload

K = P_d/P_a

ΔV_a = ascent ΔV

ΔV_d = descent ΔV

I = specific impulse

g = gravitational constant

r_a = mass at liftoff/mass in orbit (recovered)

r_d = mass at entry/mass landed on surface

λ = propellant weight/propellant + propulsion systems weight

μ = ratio of entry systems weight to weight at entry

W_{pa} = ascent propellant

W_{pd} = descent propellant

W_e = mass at entry

W_l = landed mass

W_a = mass at ascent

W_r = mass in orbit (recovered)

From the rocket equation

$$r_a = e^{\frac{\Delta V_a}{Ig}} = \frac{W_a}{W_r} \qquad (1)$$

$$r_d = e^{\frac{\Delta V_d}{Ig}} = \frac{W_e}{W_1} \qquad (2)$$

The mass of the MEM at various stages of flight is comprised of the entry system (heat shield, aeroshell structure, landing gear etc.), ascent and descent propellants, propulsion systems, and ascent and descent payload. As an example, consider the case of the single stage nonreusable MEM:

At entry the weight is comprised of

Entry and landing system	=	μW_e
Ascent propellant	=	W_{pa}
Ascent propulsion system	=	$\frac{1-\lambda}{\lambda} W_{pa}$
Descent propellant	=	W_{pd}
Descent propulsion system	=	$\frac{1-\lambda}{\lambda} W_{pd}$
Descent payload	=	P_d

so that

$$W_e = \mu W_e + \left(1 + \frac{1-\lambda}{\lambda}\right)W_{pa} + \left(1 + \frac{1-\lambda}{\lambda}\right)W_{pd} + P_d$$

or

$$W_e = \frac{1}{1-\mu}\left[\frac{W_{pa} + W_{pd}}{\lambda}\right] + KP_a \tag{3}$$

At landing the only weight change is the discharged descent propellant. Therefore

$$W_1 = \mu W_e + \frac{1-\lambda}{\lambda}W_{pd} + \frac{W_{pa}}{\lambda} + P_d \tag{4}$$

At ascent only ascent payload and ascent propulsion are returned to orbit. Surface launch weight is then

$$W_a = \frac{W_{pa}}{\lambda} + P_a \tag{5}$$

At rendezvous with propellant expended the return weight is simply,

$$W_r = \frac{1-\lambda}{\lambda} W_{pa} + P_a \tag{6}$$

The six unknowns W_{pa}, W_{pd}, W_a, W_e, W_1 and W_r can be systematically determined by the six equations 1-6. Solving for W_e, and divided by P_a, the expression for the nonreusable stage growth factor is obtained.

TABLE 1

MARS EXCURSION MODULE SCALING LAWS FOR REUSABLE AND NON REUSABLE DESIGNS

Case	Scaling Law
Nonreusable/Single Stage	$\frac{W_g}{P_a} = \frac{\left(\frac{\frac{r_a - 1}{\lambda r_a}}{1 - \frac{r_a - 1}{\lambda r_a}}\right) + k}{1 - \mu - \frac{r_d - 1}{\lambda r_d}}$
Nonreusable/Two Stage (Equal Staging Velocity)	$\frac{W_g}{P_a} = \frac{\left(1 + \frac{\frac{r_a - 1}{\lambda r_a}}{1 - \frac{r_a - 1}{\lambda r_a}}\right)^2 + k}{1 - \mu - \frac{r_d - 1}{\lambda r_d}}$
Reusable/Refuel on Orbit	$\frac{W_g}{P_a} = \frac{\left(\frac{r_a - 1}{\lambda r_a}\right) + k\left(1 - \frac{r_a - 1}{\lambda r_a}\right)}{1 - \mu + \frac{1}{\lambda}\left[\left(\frac{r_a - 1}{r_a}\right)\left(\frac{r_d - 1}{r_d}\right) - \left(\frac{r_a - 1}{r_a}\right) - \left(\frac{r_d - 1}{r_d}\right)\right]}$
Reusable/Refuel on Surface	$\frac{W_g}{P_a} = \frac{\left(1 - \mu - \frac{r_d - 1}{\lambda r_d}\right) + k\left(\mu + \frac{r_d - 1}{\lambda r_d}\right)}{1 - \mu + \mu\left(\frac{r_a - 1}{r_a}\right) + \frac{1}{\lambda}\left[\left(\frac{r_a - 1}{r_a}\right)\left(\frac{r_d - 1}{r_d}\right) - \left(\frac{r_a - 1}{r_a}\right) - \left(\frac{r_d - 1}{r_d}\right)\right]}$

List of Symbols:

P_a = Ascent Payload
W_g = Gross Vehicle Weight
k = Descent Payload/Ascent Payload
r_a = ascent mass ratio $(\Delta V_a/I_g)$
r_d = descent mass ratio $(\Delta V_d/I_g)$
λ = propellant weight/(propellant weight + propulsion system weight)
μ = ratio of entry systems weight to gross weight at entry

TABLE 2

MEM PAYLOAD ASSUMPTIONS FOR VEHICLE AND MISSION COMPARISON
PAYLOAD PER CREW MAN (1000 lbs)

Landing Mission	Nonreusable				Reusable			
	Single Stage		Two Stage		Refuel on Orbit		Refuel on Surface	
	P_a	P_d	P_a	P_d	P_a	P_d	P_a	P_d
Logistics	1	1	1	1	1.5	1.5	1.5	1.5
Self Contained Base	1	4	1	4	3	3	3	3
Cargo (To Surface)	-	-	-	-	1.5	3*	1.5	3*
Propellant Delivery (From Surface)	-	-	-	-	-	-	6*	1.5

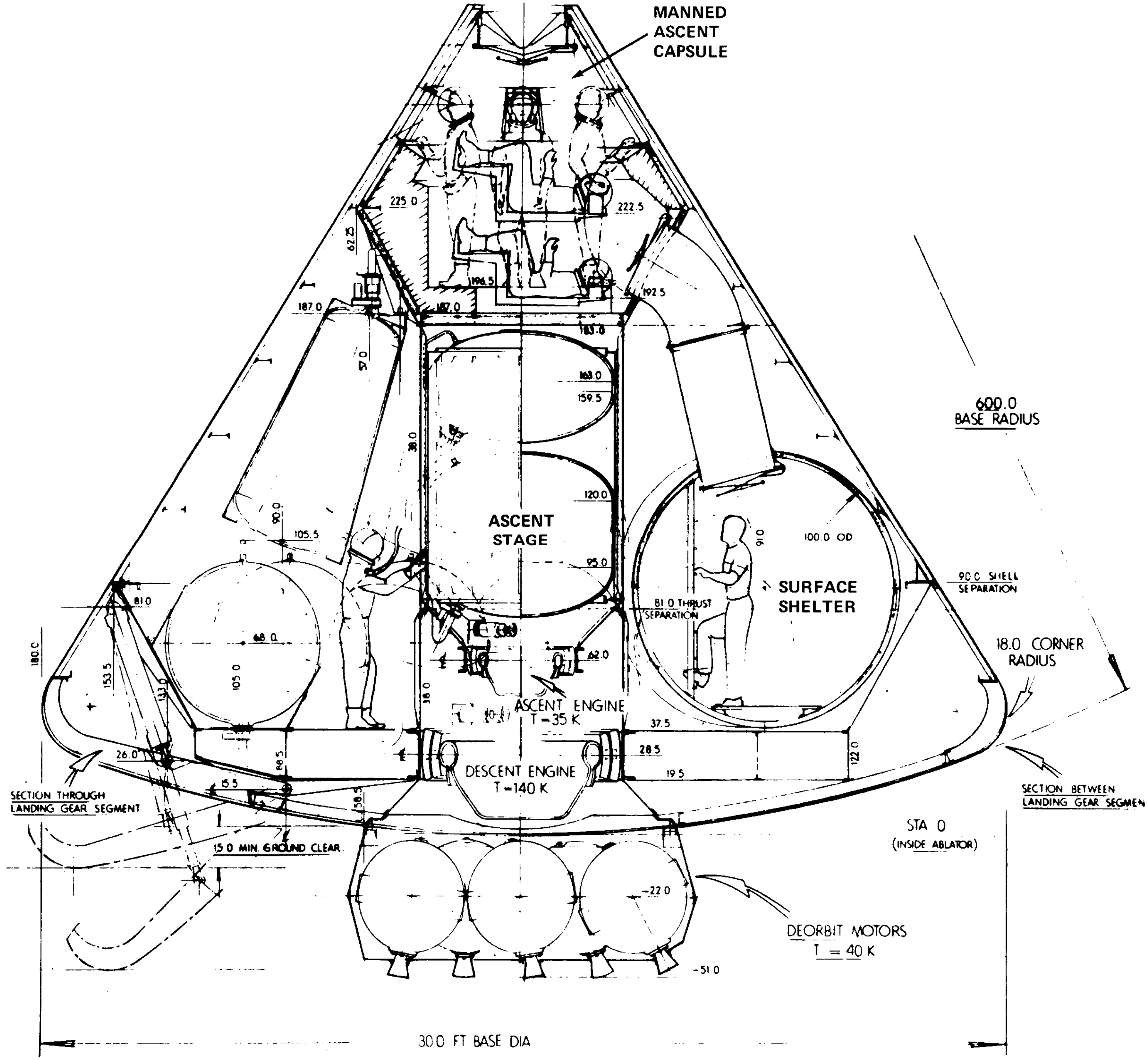
*INCLUDES 1,500 LB/MAN CREW CAPSULE

TABLE 3

THREE MAN MARS EXCURSION MODULE WEIGHT BREAKDOWN / COMPARISON BETWEEN SINGLE STAGE NONREUSABLE AND REUSABLE (FUELED ON ORBIT) VEHICLES

CONFIGURATION	LOGISTICS		SURFACE BASE	
	NONREUSABLE	REUSABLE	NONREUSABLE	REUSABLE
ASCENT CAPSULE	3000 LBS	4500 LBS	3000 LBS	– LBS
SURFACE SHELTER	–	–	6000	6000
SURFACE PAYLOAD	–	–	3000	3000
ENTRY/LANDING SYSTEMS	4100	10900	7200	22900
DESCENT PROPULSION	700	1600	1200	3400
DESCENT PROPELLANT	3800	13400	6600	27800
ASCENT PROPULSION	1300	5500	1300	9900
ASCENT PROPELLANT	7600	36800	7600	78500
GROSS WEIGHT	20500	72700	35900	151,500
TOTAL PROPELLANT WEIGHT	11 400	50200	14200	106300
μ(ASSUMMED)	.20	.15	.20	.15
λ(ASSUMMED)	.85	.89	.85	.89

NOTES
- ASSUMMED μ AND λ CHOSEN CONSISTENT WITH VEHICLE SIZE
- ASCENT VELOCITY 15000 FPS; DESCENT VELOCITY 3000 FPS
- REUSABLE LOGISTICS WEIGHT INCREASED TO ACCOMMODATE RETURN OF FIXED WEIGHT LANDING SYSTEMS



MARS EXCURSION MODULE (REFERENCE 4)

FIGURE 1

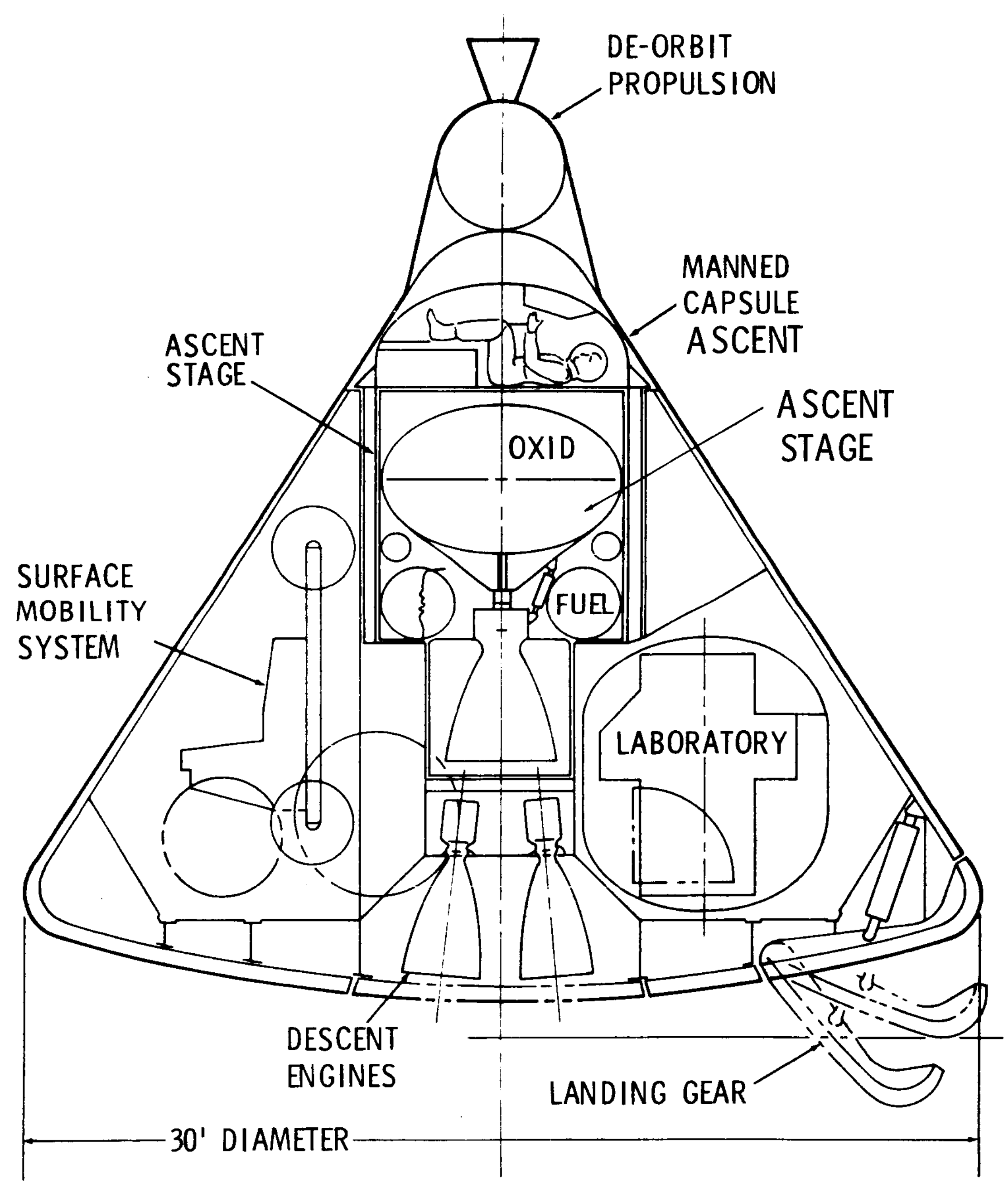


FIGURE 2 - NON REUSABLE EXCURSION MODULE (REFERENCE 5)

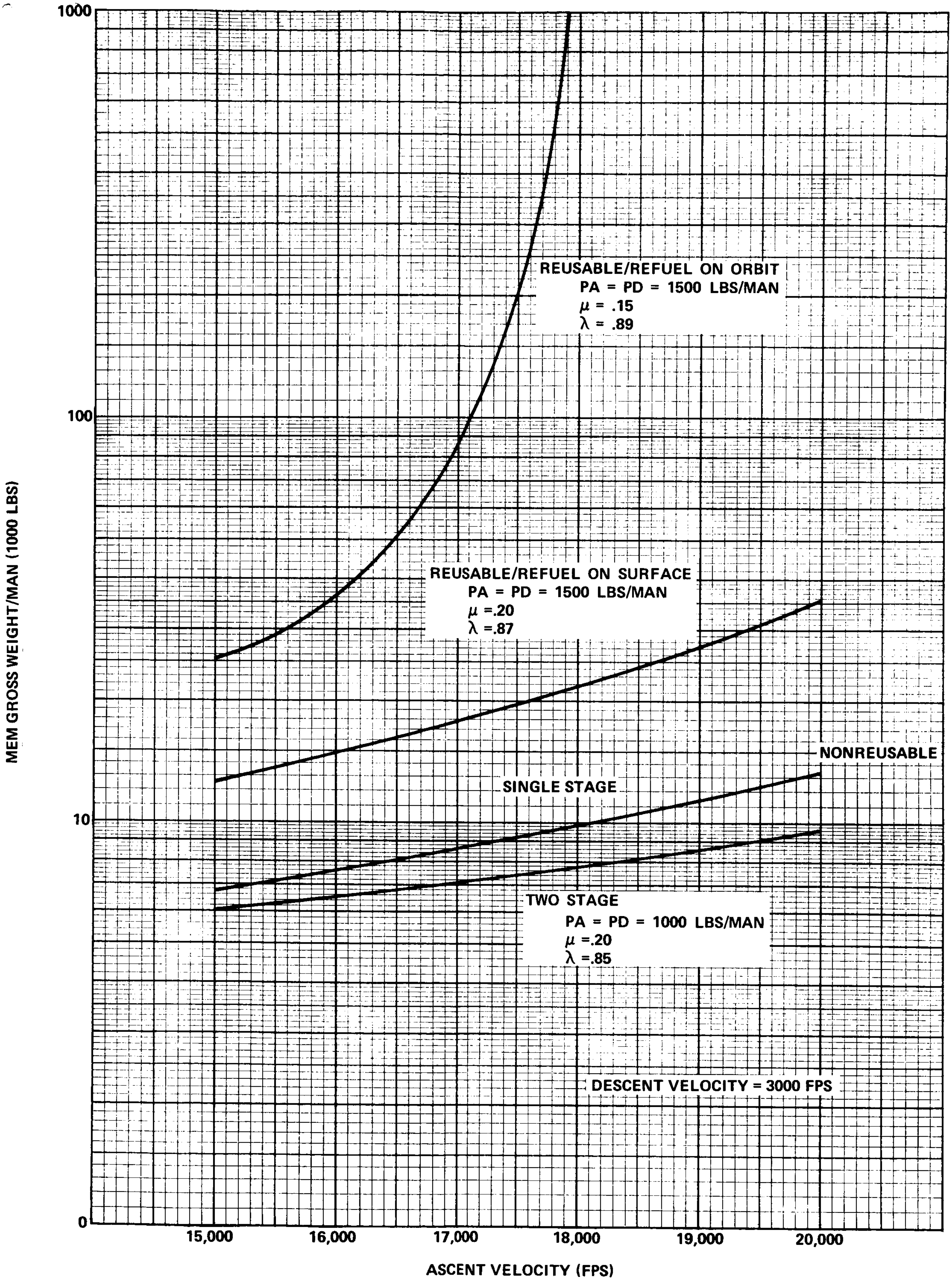


FIGURE 3 - COMPARISON OF MEM GROSS WEIGHTS FOR LOGISTICS MISSIONS AS A FUNCTION OF ASCENT VELOCITY

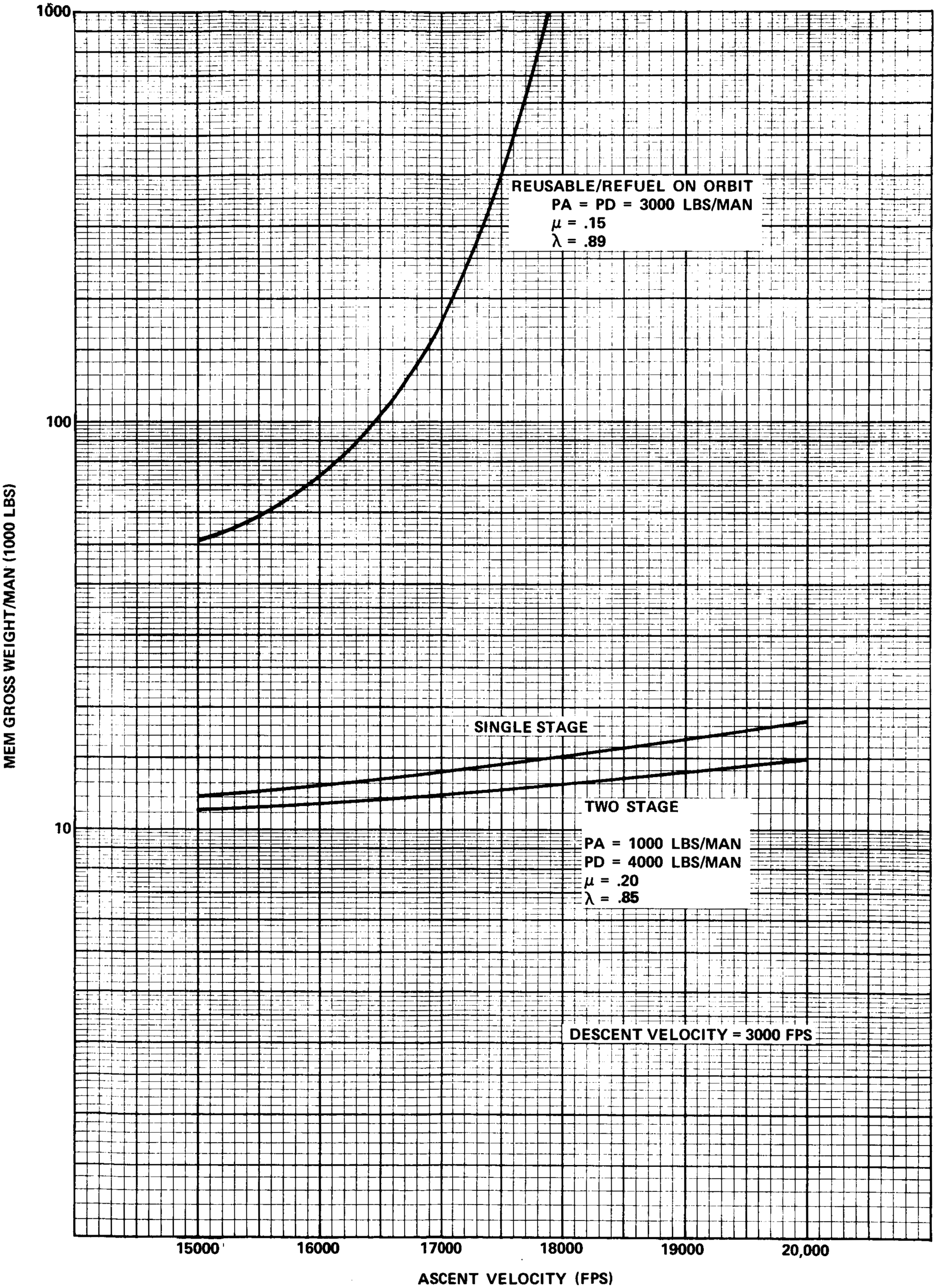


FIGURE 4 - COMPARISON OF MEM GROSS WEIGHTS FOR SELF CONTAINED MARS SURFACE BASE MISSIONS AS A FUNCTION OF ASCENT VELOCITY

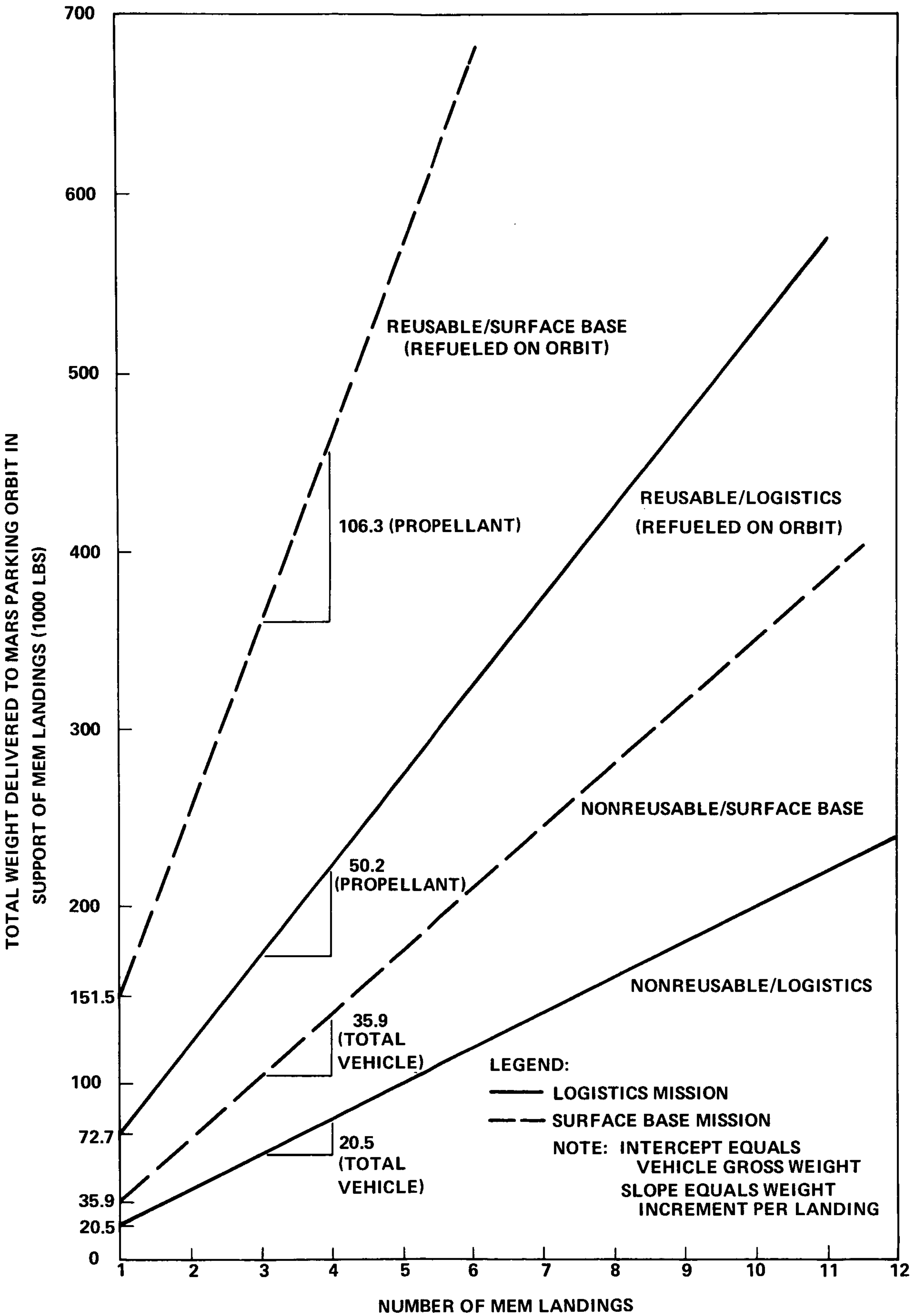


FIGURE 5 - COMPARISON OF TOTAL WEIGHT DELIVERED TO MARS PARKING ORBIT FOR REUSABLE AND NONREUSABLE 3 MAN MEM'S AS A FUNCTION OF THE NUMBER OF LANDINGS

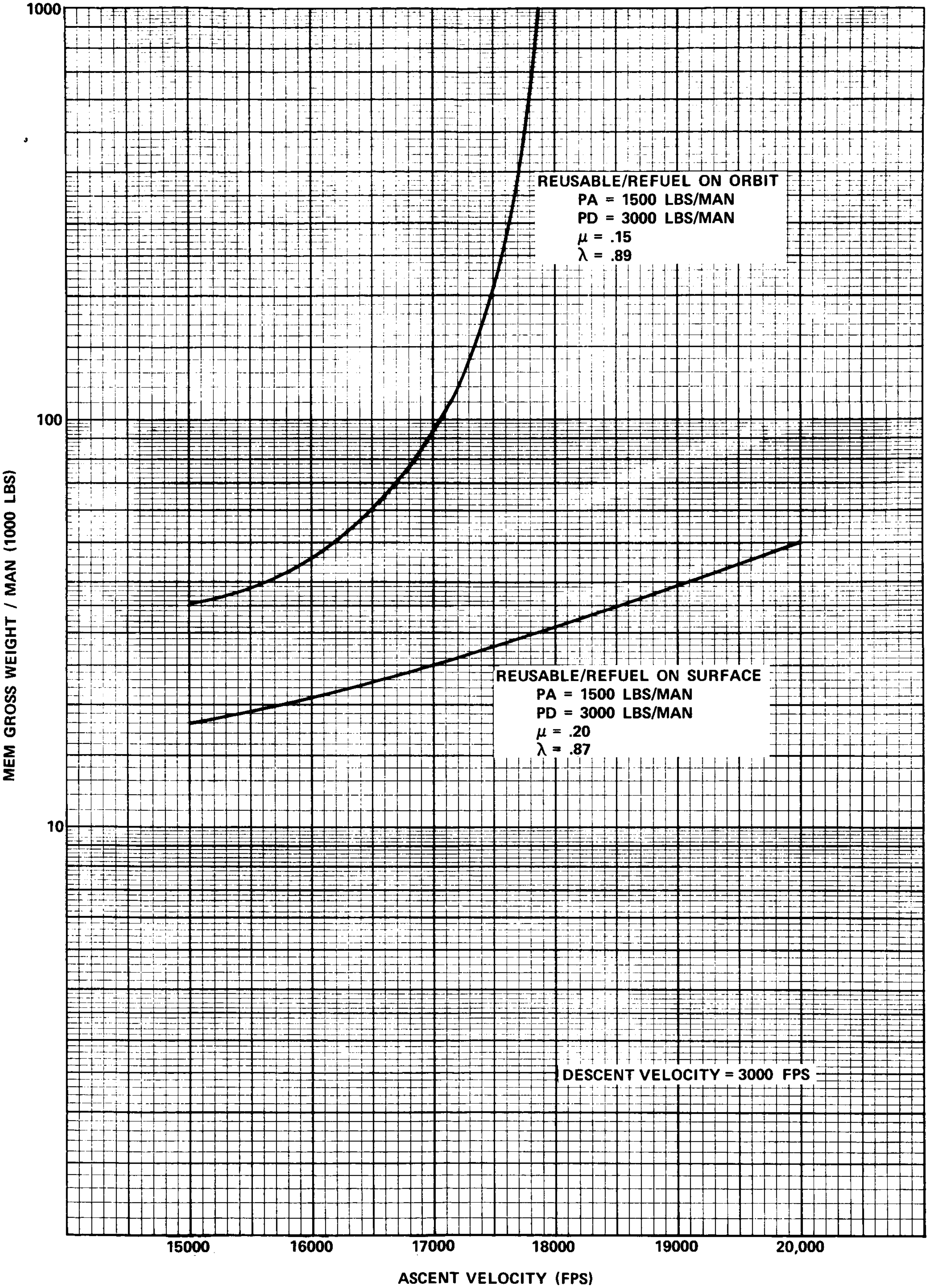


FIGURE 6 - COMPARISON OF MEM GROSS WEIGHTS FOR CARGO DELIVERY TO AND FROM THE MARTIAN SURFACE AS A FUNCTION OF ASCENT VELOCITY

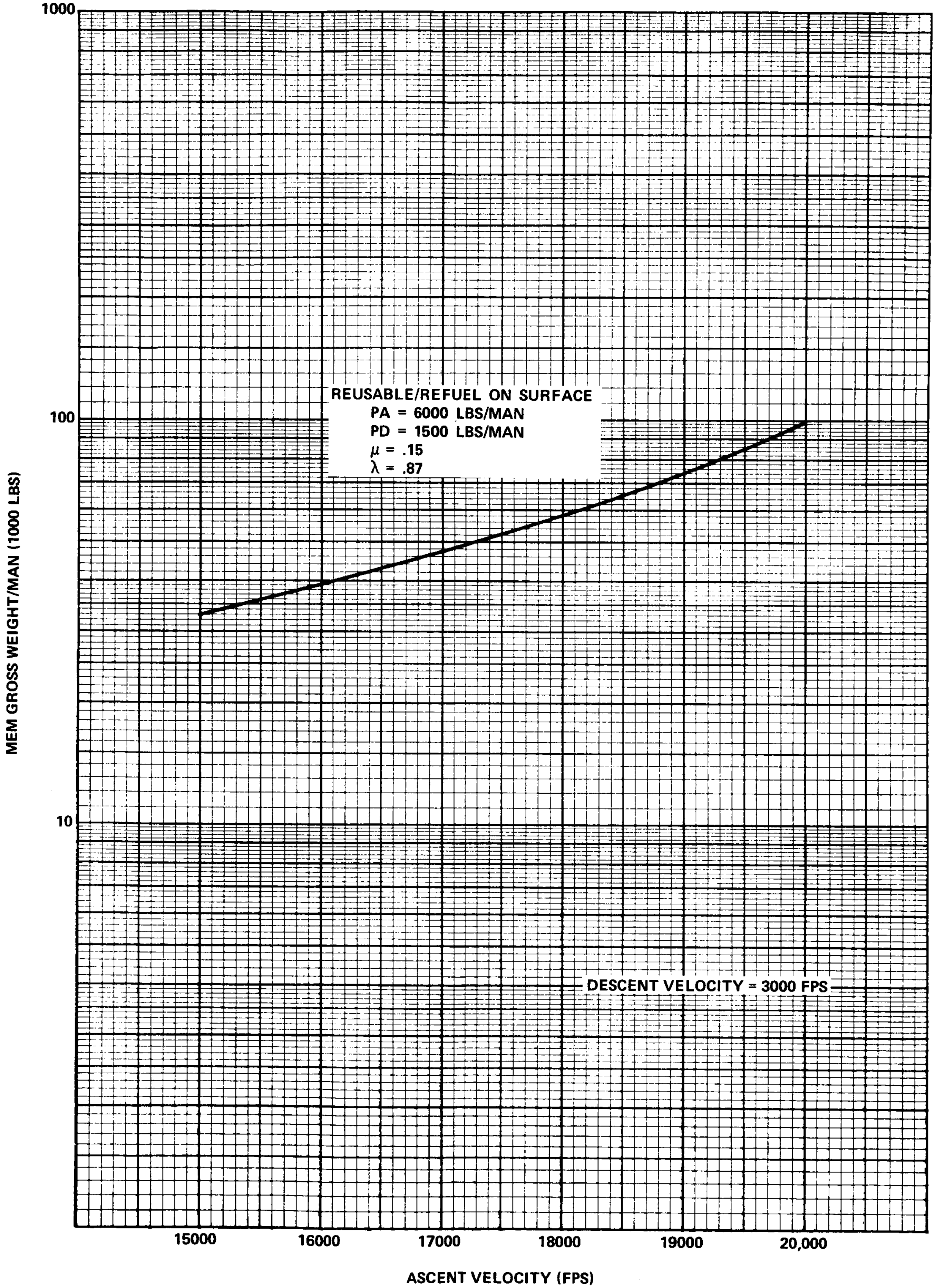


FIGURE 7 - MEM GROSS WEIGHT FOR DELIVERY OF PROPELLANT FROM THE SURFACE OF MARS TO MARS ORBIT

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